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QUIET TIME LOWEST OBSERVABLE FREQUENCY (QLOF) CALCULATION PROGR--ETC(U)
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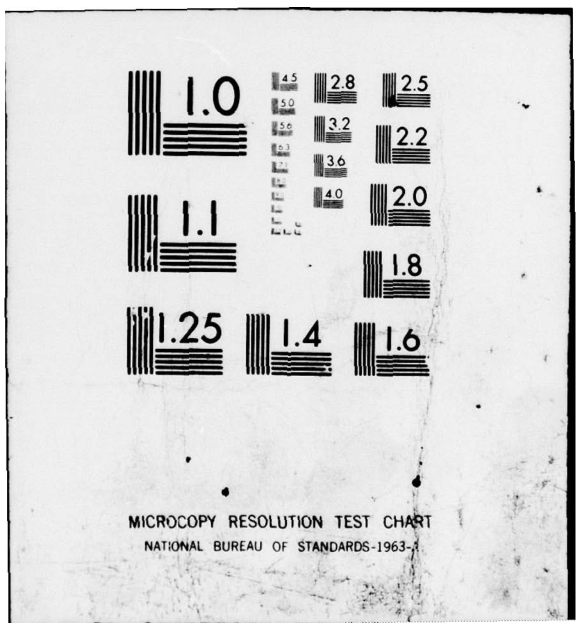
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QUIET TIME LOWEST OBSERVABLE FREQUENCY (QLOF), CALCULATION PROGRAM

PE Argo and DB Sailors

1 April 1979

Interim Report: January 1978 — January 1979

Prepared for
Naval Environmental Prediction Research Facility
Monterey, California

Approved for public release; distribution unlimited

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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Released by
J. H. Richter, Head
EM Propagation Division

Under authority of
J. D. Hightower, Head
Environmental Sciences Department

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A computer program for calculating the lowest observable frequency (LOF) for a specified hf circuit is provided. The QLOF routine has been calibrated using an oblique incident sounder system. A method for applying the results to other systems is presented.

393 159 gsm

CONTENTS

INTRODUCTION

The lowest observable frequency (LOF) for a specified hf circuit is important when one is specifying the propagation window for that circuit. This lowest frequency is an absorption controlled effect. The major cause of absorption at low and midlatitudes is the solar created ionospheric D-region. During quiet solar conditions this D-region responds directly to the amount of ionizing solar radiation reaching it. As shown in Bleiweiss (1970, 1972) and Argo and Hill (1977), this solar control is directly related to the solar zenith angle. Other relevant parameters are latitude, sunspot number, and season (calculated from Julian day), which are all described in Argo and Hill (1977).

The computer program listing presented in the appendix contains the necessary subroutines for calculating the quiet time LOF (QLOF), and a sample control routine for driving the set of subroutines. The present setup will handle up to ten (10) paths and can easily be changed up or down.

The routine "SR" also provides MOF, FOT for paths < 2000 km. Notice that by calling "QLOF", after calling "SR", the LOF is defined for pathlengths > 1000 km by the "QLOF" routine.

These routines have been checked under many conditions and the outputs compare well with the oblique incident sounder data available at NOSC.

CALCULATING THE SIGNAL LOSS MARGIN (SLM)

Because the QLOF routine was calibrated using an oblique sounder system, it is necessary to modify the calculations to provide LOFs for other systems. The signal loss margin (SLM) is the difference (in dB) between the minimum usable signal at the receiver, and the signal level expected at the same terminal under conditions of no ionospheric absorption. For the NOSC sounder systems, this SLM was found to be 37 dB. The following paragraphs describe how to estimate the SLM for propagation circuits.

The signal loss margin SLM is given by:

$$SLM = S - N - R_1 \ , \tag{1}$$

where S is the signal strength in the absence of ionospheric absorption, $N = F_{am} - 204$, F_{am} is the median value of radio noise power density F_a given in CCIR reports 322-1 and 258-2, and R_1 is the required signal to noise density ratio for the grade of service. Therefore, the SLM is given by

$$SLM = P_t + G_t + G_r - L_b - N - R_1 \tag{2}$$

where

P_t: source level, decibels above 1 watt

G_t: transmitting antenna gain (dB)

G_r: receiving antenna gain (dB)

L_b: basic transmission loss exclusive of ionospheric absorption.

We are assuming the losses in the transmitting and receiving antenna circuits are negligible. Otherwise, they would be added here. Note, also, that only L_b and N are system independent. Let

$$SLM = S' - S'' ; \tag{3}$$

where,

$$S' = P_t + G_t - G_r - R_l \tag{4}$$

and

$$S'' = L_b + N . \tag{5}$$

In at least one application it has been found that: (1) G_t is omnidirectional antenna with a gain of 4.76 dB/isotropic, and (2) G_r is a high gain antenna with a gain of 13.6 dB/isotropic. Thus,

$$S' = 18.36 + P_t - R_l . \tag{6}$$

Notice that the units of signal power in P_t and R_l must be the same (i.e., PEP or mean), and

$$S'' = L_{bf} + N = L_{bf} + F_{am} - 204, \tag{7}$$

assuming ground losses are negligible.

Here, L_{bf} is the basic free space loss, and is given by

$$L_{bf} = 32.45 + 20 \log_{10} d + 20 \log_{10} f , \tag{8}$$

where d is the propagation path length and f is the frequency in MHz. CCIR Report 258-2 gives the rural man-made noise as,

$$F_{am} = 67.2 - 27.7 \log_{10} f \tag{9}$$

and so in regions where rural man-made noise applies, S″ becomes,

$$S'' = -104.35 + 20 \log_{10} d - 7.7 \log_{10} f . \tag{10}$$

Note the S″ includes frequency, which is nominally unknown. One solution is to average the value of $\log_{10} f$ for 2.5 MHz and 30 MHz, giving $7.7 \log_{10} f = 7.22$. Another, more accurate solution, would be to modify QLOF and use the calculated sounder LOF at this point. Using the average value 7.22 in equation 10

$$S'' = -111.57 + 20 \log_{10} d . \tag{11}$$

Now, the sounder was calibrated using a 3800 km path and so for use here, d should be replaced by 3800 km.

Combining equations (6) and (11) we obtain,

$$SLM = 18.36 + P_t - 111.57 - 20 \log_{10}(3800) \tag{12}$$

$$= 58.36 + P_t - R_1$$

$$P_t = 10. \times \log_{10} (\text{power in watts})$$

and suggested values for R_1 are included in table 1 (from CCIR recommendation 339-3).

Table 1. Required signal-to-noise ratios.

50 baud telegraph	40 dB
Telephony, double side band	51 dB
Telephony, single side band	48 dB
Composite 16 channel, 75 baud each	60 dB

Remember that equation (12) has assumed specific receiving and transmitting antenna gains, and so in general

$$SLM = 40 + P_t - R_1 + G_t + G_r \tag{13}$$

REFERENCES

Argo, P. E. and J. R. Hill (1977), Lowest Observable Frequency (LOF) Model: SOLRAD Application, NELC/TN 3304, 27 Jan 1977.

Bleiweiss, M. P. (1970), Solar Influences on HF Absorption and the Resulting Hawaii to California Lowest Observed Frequency, NWC/TP 4911, May 1970.

Bleiweiss, M. P. (1977), A Prediction Scheme for the Lowest Observed Frequency (LOF) of the Guam-Northwest Cape HF Propagation Path and Eight Other Pacific Paths, NELC/TR 1851, 6 Dec 1972.

APPENDIX: QLOF CALCULATION PROGRAM

```
C      MAIN CLOF SAMPLE CONTROL ROUTINE FOR DRIVING QLOF
C  BY PAUL ARGO AND JAY HILL, AUGUST 1, 1975
       REAL K
       DIMENSION TRP(4,10),CPNT(7,10),LOF(10),SSP(2)
       DIMENSION FOT(10),MUF(10),DEL(10),SLM(10)
       INTEGER TIME(4),YEAR
C    S13=SUNSPOT NUMBER,YEAR=1973,JD=JULIAN DAY
       WRITE(6,2)S13,YEAR,JD
       TIME(1)=YEAR
       TIME(2)=JD
C    INPUT PATH ENDPOINTS
       DO 10 I=1,N
       READ(5,3)LAT1,LONG1,LAT2,LONG2
       WRITE(6,3)LAT1,LONG1,LAT2,LONG2
       TRP(1,I)=LAT1
       TRP(2,I)=LONG1
       TRP(3,I)=LAT2
       TRP(4,I)=LONG2
       SLM(I) = 37.
10      CONTINUE
       CALL PATH(TRP,CPNT,N)
       DO 100 IHOUR=1,24
       TIME(3)=IHOUR
       TIME(4)=0
       CALL SUBSOL(TIME,SSP)
       WRITE(6,70) IHOUR
   70 FORMAT(//,I4)
       CALL SP(N,CPNT,S13,TIME,SSP,SLM,LOF,FOT,MUF,DEL)
       CALL QLOF(CPNT,N,SSP,TIME,S13,SLM,LOF)
       DO 69 I=1,N
   69 DEL(I) = DEL(I)*57.29577951
       WRITE (6,12)(LOF(I),FOT(I),MUF(I),DEL(I),I=1,N)
   12 FORMAT(/4X,4F8.2)
100     CONTINUE
       STOP
       END
       SUBROUTINE QLOF(CPNT,N,SSP,TIME,S13,LOF)
C    QUIET TIME LOF FORECAST
C       THIS ROUTINE CALCULATES LOF FOR UP TO 10 PATHS
C        INPUTS:
C        CPNT(7,10) PATH CONTROL POINTS GIVEN FROM SUBROUTINE PATH
C             (1)  IF =1 PATH LT 3500KM, IF =2 THEN PATH GT 3500KM
C             (2),(3)  LAT,LONG OF MIDPATH    (RADIANS)
C             (4-7)  LAT,LONG OF POINTS 1000KM IN FROM EACH END(RADIANS)
C        N    NUMBER OF PATHS BEING CALCULATED
C        SSP(2)  LAT,LONG OF SUBSOLAR POINT (USE SUBROUTINE SUBSOL)(RADIANS)
C        TIME(4) FOUR ELEMENT INTEGER ARRAY
C             (1)  YEAR
C             (2)   JULIAN DAY
C             (3)   HOUR
C             (4)   MINUTE
C        S13  13 MONTH RUNNING AVERAGE OF SUNSPOT NUMBER
C       RETURNS:
C        LOF(10)  CALCULATED LOF IN TEN ELEMENT ARRAY USING N ELEMENTS
       REAL LOF(10),SSP(2),CPNT(7,10)
       REAL LOF1,LOF2,K1,K2,M
       INTEGER TIME(4)
C    MEDIUM(K1) AND LONG(K2) PATH CONSTANTS USED IN CONVERTING
C    ABSORPTION INTO LOF
       K1=0.58
       K2=0.70
       DO 2000 I=1,N
C    INITIALIZE LOFS TO MINIMUM(2)
```

```
      LOF(I)=2.
      LOF1=2.
      LOF2=2.
C   CHECK FOR SHORT OR LONG PATH
      IF(IFIX(CPNT(1,I)) .EQ. 2) GO TO 500
C   SHORT PATH ,USE MIDPATH FOR ABSORPTION CALC
      CALL ABSORB(S13,TIME,CPNT(2,I),CPNT(3,I),SSP,ABS,CHI,M,CHINON)
      IF(ABS .LT. 1.E-10  .OR.  CHI .GT. 1.80)GO TO 1000
      LOF(I)= K1*SQRT(ABS)*(CH(921.,CHI)/CH(921.,CHINON))**(-M)
      GO TO 1000
500    CONTINUE
C   LONG PATH  CALCULATE ABSORPTION AT EACH CONTROL POINT.
C   THE ABSORPTION USED IN LOF CALCULATION WILL BE AN AVERAGE
C   WITH CENTER WEIGHTED DOUBLE.  CHECKS AT EACH POINT FOR
C   NIGHT TIME (ZENITH ANGLE GT 1.8) OR VERY LOW ABSORPTION
C   ASSUME NO LOF LESS THAN 2 MHZ
      CALL ABSORB(S13,TIME,CPNT(2,I),CPNT(3,I),SSP,ABS,CHI,M,CHINON)
      AB1=0.
      IF(ABS .LT. 1.E-10  .OR.  CHI .GT. 1.80)GO TO 800
      AB1=ABS*(CH(921.,CHI)/CH(921.,CHINON))**(-2.*M)
800    CONTINUE
      CALL ABSORB(S13,TIME,CPNT(4,I),CPNT(5,I),SSP,ABS,CHI,M,CHINON)
      AB2=0.
      IF(ABS .LT. 1.E-10  .OR.  CHI .GT. 1.80)GO TO 900
      AB2=ABS*(CH(921.,CHI)/CH(921.,CHINON))**(-2.*M)
900   CONTINUE
      CALL ABSORB(S13,TIME,CPNT(6,I),CPNT(7,I),SSP,ABS,CHI,M,CHINON)
      AB3=0.
      IF(ABS .LT. 1.E-10  .OR.  CHI .GT. 1.80)GO TO 950
      AB3=ABS*(CH(921.,CHI)/CH(921.,CHINON))**(-2.*M)
950   CONTINUE
      LOF(I)=K2*SQRT((AB1*2. + AB2 + AB3)/4.)
      LOF(I)=SQRT((37./SLM(I))*LOF(I)**2)
1000  CONTINUE
      IF(LOF(I) .LT. 2.)LOF(I)=2.
2000   CONTINUE
      RETURN
      END
      SUBROUTINE SR(N,CP,S13,TIME,SSP,SLM ,LOF,FOT,MUF,DEL)
C  SHORT RANGE HF FORECAST USING E AND F1 LAYERS (D<2000KM)
C  FOT IS CHOSEN TO MINIMIZE MULTIPATH INTERFERENCE BY USING
C  E LAYER REFLECTIONS JUST ABOVE THE TWO HOP MUF OR AT THE
C  LOF WHEN LOF IS BELOW FOE.  WHEN SPORADIC E IS PRESENT, LOF
C  IS RECOMMENDED FOR FOT.  CALCULATION SKIPPED IF D>2000KM.
C
C  N    = NUMBER OF PATHS           CP   = PATH PARAMETERS
C  S13  = SMOOTHED SUNSPOT NUM.  TIME = TIME ARRAY
C   SLM = SIGNAL LOSS MARGIN      LOF  = LOWEST OBSERVED FREQUENCY
C  FOT  = FREQ OPTIMUM TRANS      MUF  = MAXIMUM USUABLE FREQUENCY
C  DEL  = LAUNCH ANGLE AT FOT     SSP  = SUBSOLAR POINT
C
C  BY JAY R. HILL, JULY 29, 1975
C
      INTEGER TIME(4)
      REAL MUF(10),LOF(10),FOT(10),DEL(10),SLM(10)
      DIMENSION CP(7,10),SSP(2),EMUF(2),FMUF(2)
      DATA R,YE,HE/6371.,30.,110./,RAD,FH/57.29578,1.5/
      DATA E1,E2,F1,F2/1.8,1.7,2.7,1.5/,HF/175./
      DO 1000 I=1,N
      IF(CP(1,I) .GT. 0.3139) GO TO 1000
      CALL ABSORB(S13,TIME,CP(2,I),CP(3,I),SSP,AI,CHI)
      PL = CP(1,I)/2.
      S1 = SIN(PL)
      C1= COS(PL)
      IF(CHI .LE. 1.8) GO TO 10
      LOF(I) = 2.
```

```
      FOT(I) = 2.
      MUF(I) = 2.
      DEL(I) = ATAN((C1-0.955)/S1)
      GO TO 1000
   10 CC = COS (CHI)
      CC = CC/ABS(CC)**.4
      FE = E1+E2*CC
      FF = F1+F2*CC
      YE = (HF-HE)/SQRT(1.-(FE/FF)**2)
      EF = 1.-(FE/FF)**2
      LOF(I)=SQRT(AI/SLM(I)/SQRT(1.-.9784/(1.+((C1-.985)/S1)**2)))
      L1 = 10
      L2 = 10.FF
      IF(L2 .LT. L1) GO TO 1000
      DO 40 J = 1,2
      S2 = SIN(PL/J)
      C2 = COS(PL/J)
      EMUF(J) = 1.
      FMUF(J) = 1.
        TO 40 L=L1,L2
      F = L/10.
      X = F/FE
      HV = HE+0.5*YE*(X*ALOG((1.+X)/ABS(1.-X))-2.)
      IF(X .GE. 1.0) GO TO 20
      HR = HE-YE*SQRT(1.-X**2)
      GO TO 30
   20 X = F/FF
      HR = HF-YF*SQRT(1.-X**2)
      Y = SQRT(EF/(1.-X**2))
      HV = HV+YF*X*ALOG(Y+SQRT(Y**2+1.))
   30 D = ATAN((C2-1./(1.+HV/R))/S2)
      FM = F/SQRT(1.-(COS(D)/(1.+HR/R))**2)
      IF(FM .GT. EMUF(J) .AND. F .LT. FE) EMUF(J) = FM
      IF(FM .GT. FMUF(J) .AND. F .GE. FE) FMUF(J) = FM
   40 CONTINUE
      DEL(I) = ATAN((C1-0.985)/S2)
      FOT1 = FMUF(1)*(1.-.2/FF)
      FOT2 = FMUF(2)*(1.+.2/FF)
      IF(EMUF(2) .LT. FMUF(2)) FOT2 = FMUF(2)*(1.+.2/FF)
      IF(FOT2 .LT. FOT1) GO TO 50
      IF(EMUF(1) .GT. FMUF(1)) GO TO 50
      FOT1 = FMUF(1)*(1.-.2/FF)
   50 FOT(I) = FOT2
      IF(FOT2 .LT. LOF(I)) FOT(I) = FOT1
      MUF(I) = FMUF(1)
      IF(EMUF(1) .LT. EMUF(1)) MUF(I) = EMUF(1)
      IF(FOT(I) .GT. MUF(I) .AND. LOF(I) .LT. FE) FOT(I)=LOF(I)
      IF(FOT(I) .GT. MUF(I)) FOT(I) = MUF(I) - .2
      IF( LOF(I) .LT. 2.0) LOF(I) = 2.0
      IF( FOT(I) .LT. 2.0) FOT(I) = 2.0
      IF( MUF(I) .LT. 2.0) MUF(I) = 2.0
      IF(FOT(I) .GT. FMUF(1)) DEL(I) = ATAN((C1-.9785)/S1)
 1000 CONTINUE
      RETURN
      END
      SUBROUTINE ABSORB(S13,TIME,LAT,LONG,SSP,ABSP,CHI,M,CHINON)
C     CALCULATES *ABSORPTION* AT A SPECIFIED POINT(LAT,LONG) ACCORDING TO
C     MODIFIED VERSION OF THE FORM GIVEN IN:
C        *NORMAL IONOSPHERIC ABSORPTION MEASUREMENTS*
C        ESSA PROFESSIONAL PAPER#4 BY SCHULTZ AND GALLET.
C     SEE PUBLICATION BY ARGO FOR MODIFICATIONS INCLUDED HERE.
C     MODEL INCLUDES LATITUDE,SOLAR CYCLE,SEASONALEFFECTS
C     AS WELL AS SOLAR CONTROLLED DIURNAL VARIATIONS
C       INPUTS:
C         S13  13 MONTH AVERAGE SUNSPOT NUMBER
C         TIME(4) YEAR,DAY,HR,MIN  UT
```

```
C         LAT,LONG  CONTOL POINT IN RADIANS
C         SSP(2),  SUBSOLAR POINT LAT,LONG IN RADIANS
C       RETURN:
C         ABSP ABSORPTION(NOON) IN DB(MHZ**2)
C         CHI  ZENITH ANGLE(RADIANS)
C         M  POWER OF COS(CHI) IN DIURNAL VARIATION
C         CHINON  NOON ZENITH ANGLE
      DIMENSION SSP(2)
      INTEGER TIME(4)
      REAL LAT,LONG,M,N ,LAD
      RAD=57.29577
      W=1.
      CHI=ARCOS(SIN(LAT)*SIN(SSP(1)) +COS(LAT)*COS(SSP(1))*
     #  COS(SSP(2)-LONG))
C   CALCULATE NOONTIME ZENITH ANGLE
      CHINON=SSP(1)-LAT
C
C   WINTER ANOMOLY FACTOR FOR DEC,JAN
      IF(LAT .LT. 0.5236)GO TO 100
      IF(TIME(2) .GT. 31 .AND. TIME(2) .LT. 335) GO TO 100
      W=1. +0.0275*(30.-ABS(60. -LAT*RAD))
100   CONTINUE
      N=2.*(COS(LAT))**2.40
      N=N/2.
      CSXN=(COS(CHINON))**N
C
C   CALCULATION OF ABSORPTION
C
      ABSP= 286.*W*CSXN
      IF(ABSP .LT. 1.E-11) ABSP=1.E-11
C
CCALCULATION OF M -- Z ANGLE DEP WITH LATITUDE
      LAD=LAT*RAD
      IF(LAD.GT.18.)GO TO 201
      M=0.5*(.58+(RAD*LAT/18.)*0.08)
      GO TO 300
201   CONTINUE
      IF(LAD.GT.24.)GO TO 202
      M=0.5*(0.66+ .22*(RAD*LAT-18.)/6.)
      GO TO 300
202    CONTINUE
      IF(LAD.GT.28.)GO TO 203
      M=0.5*0.88
      GO TO 300
203    CONTINUE
      M=0.44
300   CONTINUE
      RETURN
      END
      SUBROUTINE PATH(TRP,CPNT,N)
C   DETERMINES CONTROL POINTS FOR HF ABSORPTION GIVEN ENDPOINTS
C   FOR LESS THAN OR EQUAL TO TEN(10) PATHS
C     INPUTS:
C       TRP(4,10) ARE LAT,LONG OF TRANSMITTER AND RECIEVER IN DEGREES
C         N  NUMBER OF PATHS CONSIDERED (LE 10)
C     OUTPUT:
C       CPNT(7,10) PATHLENGTH AND CONTROL POINT COORDINATES(RADIANS)
C             (1)  PATHLENGTH IN RADIANS
C             (2),(3) LAT,LONG OF MIDPOINT(RADIANS)
C             (4-7) IF CPNT(1)=2 THEN ARE LAT,LONG OF POINTS 1000KM
C                     CENTERWARD OF ENDPOINTS: IF CPNT(1)=1 THEN DUMMY
      DIMENSION TRP(4,10),CPNT(7,10)
      RAD=57.29577
      DO 10 I=1,N
      DO 10 J=1,4
      TRP(J,I)=TRP(J,I)/RAD
```

```
10     CONTINUE
       DO 2000 I=1,N
C    PATHLENGTH = TR
       TR=ARCOS(SIN(TRP(3,I))*SIN(TRP(1,I))+COS(TRP(3,I))*COS(TRP(1,I))*
     #  COS(TRP(2,I)-TRP(4,I)))
       PTR=ARSIN(COS(TRP(3,I))*SIN(TRP(4,I)-TRP(2,I))/SIN(TR))
       IF(TRP(3,I) .LT. TRP(1,I))PTR=3.141593-PTR
       CPNT(1,I)=TR
C    MIDPATH
       TQ=0.5*TR
C    LATITUDE
       CPNT(2,I)=ARSIN(SIN(TRP(1,I))*COS(TQ)+COS(TRP(1,I))*SIN(TQ)*
     #  COS(PTR))
       TPC=ARSIN(SIN(TQ)*SIN(PTR)/COS(CPNT(2,I)))
C    LONGITUDE
       CPNT(3,I)=TRP(2,I)+TPQ
C    CONTROL POINTS 1000KM CENTERWARD OF TRANS,RECIEVER
       TQ=0.14791
       CPNT(4,I)=ARSIN(SIN(TRP(1,I))*COS(TQ)+COS(TRP(1,I))*SIN(TQ)*
     #  COS(PTR))
       TPC=ARSIN(SIN(TQ)*SIN(PTR)/COS(CPNT(4,I)))
       CPNT(5,I)=TRP(2,I)+TPQ
       TQ=TR-0.14791
       CPNT(6,I)=ARSIN(SIN(TRP(1,I))*COS(TQ) +COS(TRP(1,I))*SIN(TQ)
     #  *COS(PTR))
       TPC=ARSIN(SIN(TQ)*SIN(PTR)/COS(CPNT(6,I)))
       CPNT(7,I)=TRP(2,I)+TPQ
2000   CONTINUE
       RETURN
       END
       FUNCTION CH(X,Y)
C   CHAPMAN'S GRAZING INCIDENCE INTEGRAL
C   PROGRAMMED BY JAY R. HILL, AUGUST 16, 1973
C   ACCURACY <= 0.1% WHEN X(1-SIN(Y))<10 OR COS(Y)>0
C   TIMING: IBM 360/65 = 3.5 MSEC AVERAGE
       P(Z,U) = EXP(2.*X*SIN(Z*G/2.)*COS(Y+Z*G/2.)/U+Z)/U/U
       F(Z) = P(Z,SIN(Z*G+Y))
       CY = COS(Y)
       CY1 = CY-0.01745329
       IF(350.*Y .GT. X*CY1**4) GO TO 10
       CH = 1./CY
       RETURN
    10 G = (ARSIN(X*SIN(Y)/(X+ALOG(X)+20.0))-Y)/20.0
       IF(CY1 .LT. 0.0) GO TO 30
       IF(X*CY1 .LT. 40.*Y) GO TO 20
       CH=-X*SIN(Y)+G*(.1464466*F(3.414214)+.8535534*F(.5857864))
       RETURN
    20 CH=-X*SIN(Y)+G*(.5392947E-3*F(9.395071)+.03888791*F(4.536620)
     # + .3574187*F(1.745761)+.6031541*F(.3225477) )
       RETURN
    30 CH=-X*SIN(Y)+G*(.4249314E-6*F(16.27926)+.2825923E-4*F(11.84379)
     # + .7530084E-3*F(8.330153)+.009501517*F(5.552496)
     # + .06208746*F(3.401434)+.2180683*F(1.808343)
     # + .4011199*F(.7294545)+.3084411*F(.1377935) )
       RETURN
       END
       SUBROUTINE SUBSOL(TIME,SSP)
C   COMPUTE SUBSOLAR POINT
C    TIME IN HOURS AND DECIMAL FRACTIONS THEREOF
C    LAT & LONG IN DEGREES, EAST & SOUTH NEGATIVE
       DIMENSION TIME(4),SSP(2)
       INTEGER YEAR, DAY
       INTEGER HOUR
       INTEGER TIME
       REAL LAT, LONG
       RAD=57.29577
```

```
      YEAR=TIME(1)
      DAY=TIME(2)
      HOUR=TIME(3)
      DAYHR = FLOAT(DAY) + FLOAT(HOUR)/24. + FLOAT(TIME(4))/144.
      CALL ALMNAC (YEAR, DAYHR, DEC, EQNT)                              SURL 11
      LAT = DEC                                                         SURL 12
      GHA = FLOAT(HOUR) - (12.0 - EQNT/60.0)
      LONG = 15.0*GHA                                                   SURL 14
      SSP(2)=LONG/RAD
      SSP(1)=LAT/RAD
      RETURN                                                            SURL 15
      END                                                               SURL 16-
      SUBROUTINE   ALMNAC ( YEAR, DAY, DEC, EQNT )                      ALMNC  1
C  COMPUTE THE SOLAR DECLINATION AND EQUATION OF TIME                   ALMNC  2
C  INPUTS:  YEAR - INTEGER 1900 - 2000 A.D.                             ALMNC  3
C           DAY  - JULIAN DAY NUMBER PLUS DECIMAL FRACTION              ALMNC  4
C  OUTPUTS:  DEC - DECLINATION OF SUN (DEGREES)                         ALMNC  5
C           EQNT - EQUATION OF TIME (MINUTES)                           ALMNC  6
C  G.H.A. OF THE SUN MAY BE COMPUTED IN DEGREES FROM:                   ALMNC  7
C     GHA = 15.0*(HOURS-(12.0+EQNT/60.0))                               ALMNC  8
C  PROGRAMMED BY JAY R. HILL, 1969                                      ALMNC  9
      INTEGER YEAR                                                      ALMNC 10
      DATA   A0/ 0.3798/,A1/-23.0009/                                   ALMNC 11
      DATA   A2,A3,A4,A5,A6/-0.3802, -0.1550, -0.0076, -0.0025, -0.0004/ALMNC 12
      DATA   B1,B2,B3,B4,B5/ 3.5354,  0.0302,  0.0728,  0.0032,  0.0020/ALMNC 13
      DATA   C1,C2,C3,C4,C5 /0.5965, -2.9502, -0.0653, -0.1248, -0.0103/ALMNC 14
      DATA   D1,D2,D3,D4,D5/-7.3435, -9.4847, -0.3083, -0.1747, -0.0159/ALMNC 15
      DATA   ONE, TWO / 1.0,2.0/                                        ALMNC 16
      K = MOD (YEAR, 4)                                                 ALMNC 17
      DATE = 365.*FLOAT(K) + 0.0078*FLOAT(YEAR-1968)
      IF (K .NE. 0)  DATE = DATE + 1.0                                  ALMNC 19
      DATE = DATE + DAY                                                 ALMNC 20
      X = DATE/365.2500 *6.2831853                                      ALMNC 21
      SX =  SIN( X )                                                    ALMNC 22
      CX =  COS( X )                                                    ALMNC 23
      TWOCX = TWO*CX                                                    ALMNC 24
      C2X = TWOCX*CX - ONE                                              ALMNC 25
      S2X = TWOCX*SX                                                    ALMNC 26
      C3X = TWOCX*C2X - CX                                              ALMNC 27
      S3X = TWOCX*S2X - SX                                              ALMNC 28
      C4X = TWOCX*C3X - C2X                                             ALMNC 29
      S4X = TWOCX*S3X - S2X                                             ALMNC 30
      C5X = TWOCX*C4X - C3X                                             ALMNC 31
      S5X = TWOCX*S4X - S3X                                             ALMNC 32
      C6X = TWOCX*C5X - C4X                                             ALMNC 33
      DEC =  A0 + A1*CX + A2*C2X + A3*C3X + A4*C4X + A5*C5X + A6*C6X    ALMNC 34
     1          + B1*SX + B2*S2X + B3*S3X + B4*S4X + B5*S5X             ALMNC 35
      EQNT = C1*CX + C2*C2X + C3*C3X + C4*C4X + C5*C5X                  ALMNC 36
     1   +   D1*SX + D2*S2X + D3*S3X + D4*S4X + D5*S5X                  ALMNC 37
      RETURN                                                            ALMNC 38
      END                                                               ALMNC 39-
EOF..
```